PLATE FREEZER EVAPORATOR WITH CARBON DIOXIDE REFRIGERANT

FIELD OF THE INVENTION

[0001] The present invention generally relates to plate freezers, and more particularly, the invention relates to an improved design of a plate freezer evaporator for accommodating increased refrigerant pressures associated with the use of carbon dioxide as a refrigerant.

BACKGROUND OF THE INVENTION

[0002] Plate freezers are generally known in the art. They are high efficiency freezers used in a variety of applications, usually in the food processing industry. Typically, one or more spaced-apart heat-exchanger plates are located in the freezer compartment. A refrigerant passes through each of the plates to lower the temperature of the plates and the freezer compartment. The items to be frozen are then placed on the refrigerated plates. The high efficiency of plate freezers allow for a reduction in the size of the freezer compartment and for a more rapid freezing than in typical cold air freezers where the cold air is simply blown over the items until frozen.

[0003] One commonly used thermodynamic cycle for plate freezer applications is known as a vapor-compression refrigeration cycle. In this cycle, a superheated vapor refrigerant is compressed in a compressor, causing an increase in temperature. The hot, high pressure refrigerant is then circulated through a heat exchanger, called a condenser, where it is cooled by heat transfer to the surrounding environment. As a result of the heat transfer to the environment, the refrigerant condenses from a gas to a liquid. After leaving the condenser, the refrigerant passes through a throttling device where the pressure and temperature both are reduced. Upon exiting the throttling

device, the refrigerant enters a second heat exchanger, called an evaporator, located in the freezer space. In plate freezers, the evaporator includes a plate surface upon which the items to be frozen are placed. Heat transfer in the evaporator causes the refrigerant to change from a liquid phase to a saturated mixture of liquid and vapor. The vapor leaving the evaporator is then drawn back into the compressor, and the cycle is repeated.

[0004] In recent years, concern for the environment has brought about a phase-out of many refrigerants traditionally used in vapor-compression refrigeration systems. This phase-out of traditional refrigerants, such as chlorofluorocarbons ("CFCs"), occurred since their release into the environment depleted the ozone layer in the stratosphere. The use and emission of these refrigerants are now regulated through the terms of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer. The 1987 Montreal Protocol places stringent limitations on the use of CFC refrigerants. As such, there has been an immediate shift away from CFCs toward refrigerants that are more environmentally friendly.

[0005] The effort to find thermodynamically suitable refrigerants that do not adversely affect the ozone layer has led to the use of ammonia (NH_3) and carbon dioxide (CO_2) as refrigerants. These refrigerants have virtually no ozone depletion potential. Despite its environmental appeal as a refrigerant, ammonia (NH_3) has a pungent, suffocating odor and is toxic and flammable under certain conditions.

[0006] The use of carbon dioxide as a refrigerant also has certain drawbacks. One difficulty associated with the use of carbon dioxide as a refrigerant is the high working pressure of the carbon dioxide. In typical plate freezer applications, the working pressure of the carbon dioxide ranges from approximately 100 psig (690 kPa) to

about 300 psig (2070 kPa). The required refrigerant pressure associated with the use of carbon dioxide can create unacceptable stress levels in the components of a plate freezer.

[0007] An additional difficulty associated with the use of carbon dioxide is the pressure increase associated with a "shut-down" of the freezer. Freezer shut-down can occur through an interruption in the source of electrical power as well as the intentional shut-down of the freezer for defrosting or servicing. In the event that a freezer shut-down causes the carbon dioxide to reach room temperature, the refrigerant can reach pressures in excess of 1000 psig (6900 kPa). The pressure increase has been addressed through the use of a system of relief valves, such as those shown generally in United States Patent Nos. 4,986,086 and 5,042,262. However, the use of a relief valve system requires refilling of the refrigeration system with refrigerant lost through the relief valve before the freezer can be restarted.

[0008] Accordingly, it would be desirable to have an evaporator for use in a vapor-compression refrigeration cycle which uses carbon dioxide as a refrigerant. Furthermore, it would be desirable to accommodate increased working pressure when using a carbon dioxide refrigerant, as well as the increased in carbon dioxide pressure during shut-down without loss of refrigerant while maintaining stress levels in the evaporator substantially below the yield strength of the material from which the evaporator is constructed.

SUMMARY OF THE INVENTION

[0009] Accordingly, it is a general object of the invention to overcome the deficiencies of the prior art.

[00010] It is a more specific object of the present invention to provide an improved evaporator for use in a vapor-compression refrigeration cycle.

[00011] It is a further object of the present invention to provide an evaporator for use in a plate freezer in which carbon dioxide is used as the refrigerant.

[00012] It is another object of the present invention to address high refrigerant pressures associated with freezer shut-down without loss of refrigerant.

[00013] The present invention provides these and other additional objects with a plate freezer evaporator which uses carbon dioxide as a refrigerant. The evaporator is adapted to accommodate refrigerant pressures associated with ordinary freezer operation as well as the elevated refrigerant pressures, such as those encountered during freezer shut-down. The evaporator includes a longitudinally extending plate body having a first generally planar heat transfer surface, a second generally planar heat transfer surface spaced apart from the first heat transfer surface, to define a plate body solid volume. The evaporator also includes at least one longitudinally extending duct passing through the plate body solid volume to channel a refrigerant (such as carbon dioxide) maintained at a relatively high pressure. The duct has an elliptical cross-section designed to maintain a stress level in the plate body at a level substantially below the yield strength of the material from which the plate body is constructed. By forming the duct in this fashion, the evaporator accommodates refrigerant pressures associated with ordinary freezer operation as well as the elevated refrigerant pressures, such as those encountered during freezer shut-down.

[00014] Other objects and advantages will become apparent upon reading the following detailed description and upon reference to the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[00015] Fig. 1 is a perspective view of two plate freezer shelves which are comprised of a plurality of individual freezer plates;

[00016] Fig. 2 is a partially-exploded perspective view of one of the plate freezer shelves shown in Fig. 1;

[00017] Fig. 3 is a partial cut-away enlargement of a portion of Fig. 2 illustrating a refrigerant flow path;

[00018] Fig. 4 is a cross-sectional view of a freezer plate along line 4-4 in Fig. 2;

[00019] Fig. 5 is a cross-sectional view of a header along line 5-5 in Fig. 2;

[00020] Fig.6 is a cross-sectional view of a freezer plate along line 4-4 in Fig. 2 showing the displacement of the freezer plate when the internal pressure in the plate is approximately 1400 psig (9660 kPa);

[00021] Fig.7 is a cross-sectional view of a header along line 5-5 in Fig. 2 showing the displacement of the header when the internal pressure in the header is approximately 1400 psig (9660 kPa); and

[00022] Fig. 8 is a diagrammatic illustration of a mechanical refrigeration system for use in conjunction with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[00023] Generally, the present invention relates to a plate freezer evaporator, having a duct with an elliptical cross section, located between two heat exchanger surfaces which define a generally solid plate body with the elliptical duct present in each plate body. The shape of the duct allows the evaporator to accommodate carbon dioxide pressures associated with ordinary freezer operation as well

as the elevated refrigerant pressures encountered during freezer shut-down. Although described in the context of a plate freezer utilizing carbon dioxide as a refrigerant, it should be understood that the invention is not limited to such applications. The invention may be used in other refrigeration or heat transfer applications which utilize a variety of working fluids in lieu of or in addition to carbon dioxide.

[00024] Fig. 1 is a perspective view of two freezer shelves and spaced apart from one another. Each freezer shelf is adapted to receive items to be frozen between the adjacent shelves. Each of the shelves comprises of a plurality of generally rectangular freezer plates 20. Each freezer plate 20 has a length that is substantially greater than the width. Adjoining freezer plates are placed adjacent to one another along their respective lengths and attached to one another in this side-by-side orientation to create a plate freezer shelf as shown in Figs 1 and 2. The resulting plate freezer shelf is then connected to an inlet header 32 and an outlet header 34.

[00025] During ordinary operation of a plate freezer, carbon dioxide is pumped into the freezer plates 20 from the liquid manifold 28 through one of the several inlet hoses 30. The carbon dioxide then flows through a serpentine circulation duct (reference numeral 50 in Figs. 2, 3, 4 and 6) located in each of the freezer plates 20. After the carbon dioxide has passed through the entire length of the circulation duct located in each freezer plate 20, it flows into the outlet headers 34.

[00026] Due to heat transfer to the carbon dioxide from the items located on the plate freezer to be frozen, the carbon dioxide exits the outlet headers 34 as a saturated mixture of liquid and vapor. This saturated mixture enters the collecting manifold 38 through one of the

outlet hoses 36 leading from the outlet headers 34 to the collecting manifold 38. The saturated mixture of liquid and vapor carbon dioxide then exits the collecting manifold 38 towards the primary receiver 24 shown by flow arrow 26c in Fig. 8.

[00027] A plurality of freezer plates 20 are attached to one another and are positioned in spaced-apart relation to create a plurality of plate freezer shelves. The plurality of freezer plates 20 which comprise a plate freezer shelf are located within the sealed freezer space. The items to be frozen are placed on a freezer plate shelf. Although Fig. 1 illustrates the plate freezer shelf as being comprised of thirteen individual freezer plates 20, any number of freezer plates 20 can be used to create a freezer plate shelf of the desired size. Additionally, a plurality of freezer plate shelves can be located in a particular freezer space to maximize the number of items which a given freezer volume can accommodate for freezing.

[00028] Fig. 2 is a partially-exploded perspective view of the freezer plates 20 assembled to form a single plate freezer shelf. Fig. 2 illustrates the circulation of the carbon dioxide from the inlet header 32, through the freezer plates 20 and into the outlet header 34.

[00029] In Fig. 2, the carbon dioxide enters the inlet header 32 through the inlet hose 30. Located in the inlet header 32 is a plurality of inlet header apertures 48. Each inlet header aperture 48 is in fluid communication with a serpentine circulation duct 50 located within each freezer plate 20. The fluid communication between the apertures 48 and the circulation duct 50 allows carbon dioxide to flow from the inlet header 32 into the freezer plate 20. Shown in Fig. 2, each individual freezer plate 20 has a single serpentine circulation duct 50 with each duct having a single inlet 52 and a single outlet 56 with each inlet 52 in

fluid communication with an inlet header aperture 48. The serpentine-shaped circulation duct 50 allows carbon dioxide to flow through the freezer plate 20 while having sufficient residence time within the freezer plate to allow heat transfer to occur and cool the freezer plate 20.

[00030] Although Fig. 2 illustrates each freezer plate 20 as having a single serpentine circulation duct 50 with a single inlet 52 and outlet 56, it will be appreciated by those of skill in the relevant art that each freezer plate 20 may have multiple serpentine ducts 50 and may also have multiple inlets and outlets and still be within the scope of the present invention.

[00031] Upon flowing through the entire length of the circulation duct 50, the carbon dioxide exits the freezer plate 20 and enters the outlet header 34. The outlet header 34 contains a plurality of outlet header apertures 54 which are in fluid communication with a circulation duct outlet 56 such that the carbon dioxide can flow from the circulation duct 50 into the outlet header 34 through the outlet header apertures 54. The carbon dioxide then flows the length of the outlet header 34 and exits through the outlet hose 36 into the collecting manifold 38 shown in Figs. 1 and 8.

[00032] Fig. 3 is a partial cut-away enlargement of a portion of Fig. 2 illustrating a flow path of carbon dioxide from the inlet hose 30, through the inlet header 32 and into the freezer plate 20. In particular, the carbon dioxide enters the inlet header 32 through the inlet hose 30 from the liquid manifold 28 (shown in Figs. 1 and 8). The carbon dioxide enters the first channel 58 of the inlet header 32 and flows through a series of apertures 60 in the web 62 which separates the first channel 58 from the second channel 64 of the inlet header 32. Upon entering the second channel 64 of the inlet header 32, the carbon dioxide flows through the inlet header aperture 48 and into the freezer plate 20

through a circulation duct inlet 52. The direction of flow of the carbon dioxide from the inlet header 32 into the freezer plate 20 is indicated by the arrow 66.

[00033] Although Fig. 3 illustrates the inlet header 32 separated from the freezer plate 20, this is merely for illustrative purposes to show the carbon dioxide flow from the inlet header 32 into the freezer plate 20. In practice, the inlet and outlet headers 32, 34 will be securely fastened to the freezer plates 20 by welding or other suitable means to prevent carbon dioxide leakage between the inlet header 32 and an individual freezer plate 20.

[00034] The carbon dioxide enters the freezer plate 20 through the circulation duct 50. The circulation duct 50 is shown in Figs. 2, 3, 4 and 8 to have an approximately elliptical cross-sectional shape. The cross-sectional design of the circulation duct 50 of the present invention eliminates corners which are present in rectangular ducts and act as discrete regions of unacceptably high stress when carbon dioxide is used as a refrigerant. With the use of the cross-sectional shape of the present invention, the stress concentration factor is significantly reduced from the level encountered with the use of prior circulation ducts. The presence of elliptical ducts allows the present invention to safely operate with carbon dioxide as a refrigerant. Additionally, the use of nearly elliptical circulation ducts significantly reduces the amount of outward displacement experienced by the mid-point of the circulation duct during the elevated internal pressures associated with the use of carbon dioxide.

[00035] Upon entering the freezer plate 20, the carbon dioxide flows through the serpentine circulation duct 50 as shown by the arrows 68 in Fig. 3. When the first end of the circulation duct 50, located towards the outlet end of the freezer plate, is encountered by the carbon dioxide,

the serpentine shape effects a 180 degree turn in the carbon dioxide and directs it back towards the inlet header 32. When the carbon dioxide reaches the inlet header 32 it then crosses over through another 180 degree turn to the next elliptical duct, as shown by the arrows 70, to flow back towards the outlet header. This serpentine flow is repeated numerous times, preferably seven with six 180 degree turns, although only a single 180 degree turn is illustrated in Fig. 3.

[00036] Because the operating pressure of the carbon dioxide is higher than that of ammonia (NH_3), the headers 32,34 must be sufficiently robust to withstand the increased operating pressure as well as the elevated pressures encountered when the refrigeration system is powered down. For example, placing the web 62 between the first and second channels 58, 64 increases the structural integrity of the headers 32, 34 so that the headers can safely handle the elevated pressures associated with the use of carbon dioxide as the refrigerant.

[00037] Although only one pass of the carbon dioxide through the freezer plate is illustrated in Fig. 3, a person of skill in the relevant art would understand that multiple passes would be desirable to enhance the overall freezer efficiency. In the preferred mode of operation, the refrigerant makes seven parallel passes with six 180 degree turns through each freezer plate before exiting the freezer plate 20 and entering the outlet header. The seven preferred passes of the refrigerant through the elliptical serpentine duct 50 includes having the refrigerant flow substantially toward the outlet on four of the passes and substantially towards the inlet on three of the passes thus causing the refrigerant to exit the freezer plate on the opposite end from where it enters as shown in Fig. 2.

[00038] The repeated circulation of the carbon dioxide through the serpentine duct 50 allows the carbon dioxide to absorb heat that has been transferred from the items located on the freezer plate 20 which are to be frozen. Additionally, Fig. 3 illustrates the structures associated with the introduction of carbon dioxide into the freezer plates 20 through the inlet header 32. A substantially similar structure is also present (although not illustrated) on the outlet end of the freezer plates 20.

[00039] Fig. 4 is a cross-sectional view of a freezer plate along line 4-4 shown in Fig. 2. Fig. 4 illustrates the elliptical cross-section of the circulation duct 50 located in each freezer plate 20. Although the cross-section shown in Fig. 4 illustrates only three elliptically shaped ducts 50, any number of ducts, preferably seven, may be located with an individual freezer plate 20.

[00040] The elliptical ducts 50 are formed in the freezer plate 20 which is a solid but for the presence of the ducts 50 passing through the freezer plate 20. The elliptical ducts each have a first diameter 72 and a second diameter 74. The ratio of the first diameter 72 to the second diameter 74 ranges from approximately 2.0 to approximately 2.35, preferably between about 2.1 and about 2.25 and most preferably about 2.21.

[00041] As shown in Fig. 4, as well as Figs. 1, 2, 3 and 6, the freezer plate 20 has a first generally planar heat transfer surface 80 for supporting items to be frozen. The freezer plate 20 also has a second generally planar heat transfer surface 82 spaced apart from the first heat transfer surface 80 to define a solid volume therebetween.

[00042] The freezer plate 20 has a thickness 76 and a width 78. The freezer plate thickness 76 multiplied by the freezer plate width 78 yields the total cross-sectional freezer plate area. Additionally, each ellipse shown as a

cross section of the ducts 50 in Fig. 4 has an area and the sum of the area for all ellipses present in the cross-section of an individual freezer plate is the total ellipse area. The ratio of the total ellipse area to the total cross-sectional freezer plate area ranges from approximately .57 to approximately .67, preferably between about .6 and about .64 and most preferably about .63.

[00043] Due to fundamental thermodynamic differences between ammonia (NH_3) and carbon dioxide (CO_2), including enthalpy and density, the pressure of the carbon dioxide in the freezer plate must be significantly higher to achieve a similar freezing capacity relative to ammonia. This increase in refrigerant pressure combined with prior freezer plate designs placed the peak stress level of the freezer plate at or above the yield strength of aluminum 6061-T6, the material from which freezer plates are preferably constructed. Additionally, the displacement experienced by prior freezer plate designs with the increase in refrigerant pressures, was unacceptable. However, it was not desirable to alter the material from which the freezer plates were constructed due to the favorable thermal conductivity, costs, manufacturing experience and industry acceptance of aluminum freezer plates.

[00044] By creating an elliptical duct 50 in an otherwise solid freezer plate as shown in Fig. 4, the maximum stress level in the freezer plate was dramatically reduced. The reduction in freezer plate stress substantially below the yield strength of aluminum 6061-T6 allowed the use of carbon dioxide as a refrigerant while still allowing for an acceptable factor of safety.

[00045] Moreover, the use of an elliptical duct 50 has yielded another advantage. In a plate freezer, the minimum operating temperature of the carbon dioxide is -50° F (-46° C). This temperature permits the use of inexpensive

carbon steel on some components as well as being sufficiently far away from the triple point of carbon dioxide (-69° F; -56° C) at the working pressure. Because the operating temperature of the carbon dioxide (-50° F; -46° C) is lower than that for ammonia (-40° F; -40° C), the thermal efficiency of a freezer plate using carbon dioxide with elliptical ducts 50 is increased over the use of ammonia and prior freezer plate designs.

[00046] Fig. 5 is a cross-sectional view of a header along line 5-5 shown in Fig. 2. Fig. 5 illustrates the two-channeled header used in conjunction with the carbon dioxide refrigerant. Although shown as a cross-sectional view of the outlet header 34 in Fig. 2, the construction of the inlet header 32 is identical.

[00047] As shown in Fig. 2 and Fig. 5, the carbon dioxide exits a freezer plate 20 through a circulation duct outlet 56 and into the second channel 64 through the outlet header aperture 54. The first channel 64 and the circulation duct outlet 56 are in fluid communication through the outlet header aperture 54 to allow the carbon dioxide to flow from the freezer plate 20 into the outlet header 34. Apertures (identified in Fig. 3 with reference numeral 60) located in the web 62 which separates the first channel 64 from the second channel 58, allow the carbon dioxide to flow from the first channel 64 into the second channel 58. The carbon dioxide then exits the second channel 58 through an outlet hose 36 into the collecting manifold 38 as shown in Figs. 1 and 8.

[00048] With the use of carbon dioxide as a refrigerant and the concomitant increase in refrigerant pressure combined with inadequate prior inlet and outlet header designs, the peak stress levels in the header were above the yield strength of aluminum 6061-T6 from which the headers are preferably constructed.

[00049] However, by designing a more robust header for use with the carbon dioxide refrigerant, including the addition of the web 62, the maximum stress level in each header was dramatically reduced. This reduction in maximum header stress, to a level substantially below the yield strength of aluminum, allowed the use of carbon dioxide as the refrigerant while still maintaining an acceptable factor of safety and minimizing the amount of material required for constructing the headers.

[00050] Fig. 6 is a cross-sectional view of a freezer plate along line 4-4 in Fig. 2 showing the magnified displacement of a freezer plate when the internal pressure in the elliptical ducts is approximately 1400 psig (9660 kPa).

[00051] Fig. 6 is an illustration from a finite element analysis showing the manner in which the elliptical ducts 50 and the first and second heat transfer surfaces 80, 82 of the freezer plate 20 deflect when the internal pressure in the elliptical ducts is approximately 1400 psig (9660 kPa). Based upon this finite element analysis, the areas of the freezer plate cross section with the highest stress and maximum deflection are identified with reference numeral 84 in Fig. 6. The elliptical ducts 50 of the present invention has reduced the magnitude of maximum stress and deflection 84 experienced by the freezer plate at 1400 psig (9660 kPa) by a factor of approximately three.

[00052] The use of the elliptical ducts has placed the maximum stress in the freezer plate 20 at a level substantially below the yield strength of the material from which the freezer plate 20 is typically constructed. With the significant reduction in the maximum stress due to the use of the elliptical ducts 50, the carbon dioxide could be used as a refrigerant without replacing the aluminum 6061-T6. More importantly, using elliptical ducts to reduce the

maximum stress to a level substantially below the yield strength, a factor of safety is now designed into the freezer plate 20.

[00053] Fig. 7 is a cross-sectional view of an outlet header 34 showing the magnified displacement of a freezer plate when the internal pressure within the header is approximately 1400 psig (9660 kPa). Although described in terms of the outlet header 34, the description which follows is equally applicable to the inlet headers 32.

[00054] Fig. 7 is an illustration from a finite element analysis showing the manner in which the first channel 58 and the second channel 64 deflect when the internal pressure in the channels is approximately 1400 psig (9660 kPa). Based upon this finite element analysis, the areas of the header cross section with the highest stress and maximum deflection are identified with reference numeral 86 in Fig. 7. The presence of the web 62 in the header 34 has reduced the region of maximum stress and deflection 86 experienced by the freezer plate when subjected to a refrigerant pressure of approximately 1400 psig (9660 kPa) by a factor of approximately five.

[00055] The use of the two-channel header has placed the maximum stress in the header 34 at a level substantially below the yield strength of the material from which the header 20 is typically constructed. With the significant reduction in the maximum stress due to the use of the two-channel header, the carbon dioxide could be used as a refrigerant without replacing the aluminum 6061-T6. More importantly, using a two-channel header to reduce the maximum stress to a level substantially below the yield strength, a factor of safety is now designed into the header 34.

[00056] Fig. 8 is a diagrammatic illustration of the mechanical refrigeration system 10 for use in conjunction

with the present invention. In operation, a pump 22 draws liquid carbon dioxide from a primary receiver 24 in the direction shown by flow arrows 26a. Liquid carbon dioxide is then discharged from the pump 22 (shown by flow arrows 26b) into the liquid manifold 28. The cold liquid carbon dioxide passes from the liquid manifold 28 into the freezer plates 20 through one of several inlet hoses 30 which connect the liquid manifold 28 with the individual inlet headers 32. The liquid carbon dioxide refrigerant passes through an inlet header 32 and into one of the freezer plates 20.

[00057] The freezer plates 20 are located in the freezer space and the items to be frozer (not illustrated herein) are placed on top of a freezer plate 20 to allow freezing to occur. A plurality of individual freezer plates 20 are placed in side-by-side orientation as shown in Figs. 1 and 2. The freezer plates 20 are then fastened together, usually by welding to produce a freezer plate shelf for supporting the items to be frozen. The individual freezer plates 20 are generally solid aluminum 6061-T6 except for the elliptical duct formed into each freezer plate for circulating the refrigerant. Heat transfer from the items to be frozen through the freezer plates 20 and into the carbon dioxide causes some of the liquid carbon dioxide to evaporate. This evaporation produces a saturated mixture of liquid and vapor carbon dioxide which exits the freezer plates 20 through the outlet headers 34. The saturated mixture of liquid and vapor carbon dioxide then exits the outlet headers 34 through outlet hoses 36 and proceeds into the collecting manifold 38.

[00058] The liquid/vapor carbon dioxide exits the collecting manifold 38 as shown by flow arrow 26c and returns to the primary receiver 24 to repeat the cycle with the liquid portion of liquid/vapor carbon dioxide which has been returned to the primary receiver 24.

[00059] The continuous conversion of a portion of the liquid carbon dioxide present in the primary receiver 24 to gaseous carbon dioxide would eventually convert all of the liquid carbon dioxide to gaseous carbon dioxide and prevent the continued cooling of the freezer plates 20. To replenish the liquid carbon dioxide in the primary receiver 24, the gaseous carbon dioxide located in the primary receiver 24 is pumped from the primary receiver 24 by a compressor 40 in the direction shown by flow arrows 42a in Fig. 8. The super-heated vapor drawn from the primary receiver is then compressed by the compressor 40 causing an increase in pressure and temperature of the carbon dioxide. The hot, high-pressure carbon dioxide is then circulated through a condenser 44 in the direction shown by flow arrow 42b. The carbon dioxide is then cooled through heat transfer to the environment in the condenser 44 to form liquid carbon dioxide which flows from the condenser 44 in the direction shown by flow arrow 42c. The resulting liquid carbon dioxide is then collected in an intermediate receiver 46. The liquid carbon dioxide is then circulated from the intermediate receiver 46 to the primary receiver 24 in the direction shown by flow arrow 42d, thereby, replenishing the liquid carbon dioxide in the primary receiver 24.

[00060] Accordingly, an evaporator for use in a vapor-compression refrigeration cycle meeting the aforestated objectives has been described. It should be understood, however, that the foregoing description has been limited to the presently contemplated best mode for practicing the invention in a specific application using carbon dioxide as a refrigerant. It will be apparent to one of skill in the relevant art that various modifications may be made to the invention, with the attainment of some or all of the advantages of the invention. Accordingly, the invention should only be limited by the appended claims and

equivalents thereof, which claims are intended to cover such other variations and modifications as come within the spirit and scope of the invention.